ASIAEX Horizontal Internal Wave Array

Timothy F. Duda
Applied Ocean Physics and Engineering Department, MS 11
Woods Hole Oceanographic Institution, Woods Hole, MA 02543
Phone: (508) 289-2495 Fax: (508) 457-2194 Email: tduda@whoi.edu

James D. Irish
Applied Ocean Physics and Engineering Department, MS 17
Woods Hole Oceanographic Institution, Woods Hole, MA 02543
Phone: (508) 289-2732 Fax: (508) 457-2154 Email: jirish@whoi.edu

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LONG TERM GOALS

Our goals are to understand the dynamics and behavior of continental shelf and slope internal gravity waves, the physics of acoustic/internal wave interaction at those sites, and the acoustic signal variability resulting from such interaction.

OBJECTIVES

We wish to fully describe internal waves and acoustic/internal wave interactions observed during the spring 2001 ONR Asian Seas International Acoustics Experiment (ASIAEX), South China Sea Volume Interaction Component. We also wish to determine the primary features of and the dominant dynamical effects displayed by internal waves propagating past the acoustic equipment using many inexpensive moorings, supplementing data obtained by other less-numerous traditional moorings. The behavior of internal waves and tides at the ASIAEX site will be compared with that at other experimental sites such as the New England and European shelves.

APPROACH

Our research uses temperature time-series data from many moorings in an area having rich nonlinear wave activity: The ASIAEX 2001 area of the South China Sea between Taiwan and Hong Kong. Our work differs from other recent experiments simply by having more moorings. Unfortunately, in previous studies of nonlinear internal wave evolution in coastal waters, the spacing between the moorings has typically been either too broad to fully resolve the development of the waves, or the moorings were sufficiently close together but not always in the most interesting place from a dynamical standpoint. Our approach improves measurement and quantification of mode-one internal wave behavior. It is not suitable for internal waves of high vertical wavenumber. It must be emphasized that these temperature measurements do not stand alone. Twelve other moorings with physical oceanographic sensors were placed in the area, with eleven recovered, and daily Seasoar surveys were made in the area. Two technical approaches have been emphasized to allow deployment of eighteen small moorings during ASIAEX. The first is the use of less-durable, cheaper mooring technology than is typically employed, resulting in the Locomoor design (Low-cost). The second is

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14. ABSTRACT
Our goals are to understand the dynamics and behavior of continental shelf and slope internal gravity waves, the physics of acoustic/internal wave interaction at those sites, and the acoustic signal variability resulting from such interaction.

15. SUBJECT TERMS

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the trading away of dense vertical sampling density in order to gain horizontal coverage without increasing cost.

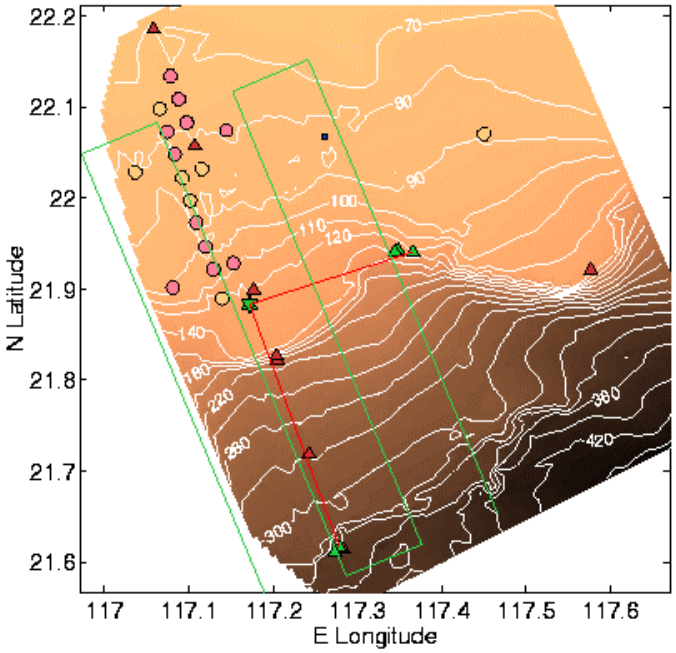

Figure 1. ASIAEX South China Sea site. The Locomoor/HIWAY is shown with circles. Eleven Loco's were recovered (pink) and seven were lost. The Seasoar track is shown in green. The red lines show acoustic transmission paths for moored components, with the HLA/VLA receiver at the vertex, and five sources at the other sites. The red triangles show physical oceanographic moorings additional to the Locomoor arra,y which carried ADCP's at six sites for measurement of internal wave velocities, including the four sites nearest HIWAY. Depths are in meters.

WORK COMPLETED

During FY01 we deployed eighteen Locomoors in the vicinity of the WHOI/NPS Horizontal/ Vertical Line Array acoustic receiver, forming the Horizontal Internal Wave Array (HIWAY), Figure 1. Eleven were successfully recovered. The figure shows the other ASIAEX moorings, many of which had ADCP's, including the four nearest HIWAY. The ADCP velocity data are highly complementary to the HIWAY/Locomoor temperature data. The instrumentation was in the water from 22 April until 18 May 2001.

The Locomoors had no surface expression (i.e. were not visible) in order to safeguard them from human interference. The design was inexpensive and lightweight in comparison with the other ASIAEX moorings. At the upper end were ten plastic floats and an acoustically controlled recovery float and line pack held together with an aluminum frame. Beneath was a synthetic rope attached to a 933 lb anchor, with three thermometers taped and tie-wrapped to the rope. The thermometers were placed in the main thermocline so that high-frequency deviations could be converted to isotherm displacement.

The high quantity of moorings allows continuous two-dimensional horizontal wave mapping, allowing study of wave formation, wavefront interaction, refraction, and energy flux. Towed hydrographic data

were collected daily for eight days along the track shown in Figure 1 by Glen Gawarkiewicz and colleagues, which may allow accurate calculation of internal-wave displacements. This can be tested at the other moorings with vertically dense thermometers. The HIWAY data will be combined with other moored sensors in the area and with synthetic aperture radar images to give the best possible temporally continuous picture of the wavefield. An explanation of equipment failures and mooring operations can be found in last year's report.

Much of the data set has been analyzed. The Horizontal Array data were used to track the speed and direction of strong nonlinear "transbasin" solitary-type internal waves, which propagate long distances across the South China Sea, into waters less than 120 meters deep. These waves were tracked along the line of deeper moorings after entering the ASIAEX experimental site, then tracked through the two groups of Loco moorings. Under the auspices of this project the PI has also analyzed data collected with the other ASIAEX moorings in coordination with the other ASIAEX PI's. The Horizontal Array data have been directly compared to variability at hour to day time scales of acoustic signal levels, and acoustic signal scintillation indices in the Duda *et al*. acoustic intensity manuscript submitted to the *IEEE Journal of Oceanic Engineering* special issue on the Asian Marginal Seas, listed later under Publications. The data have also been incorporated in the Duda *et al.* internal tide and internal wave manuscript submitted to the same issue, also listed at the end of this report.

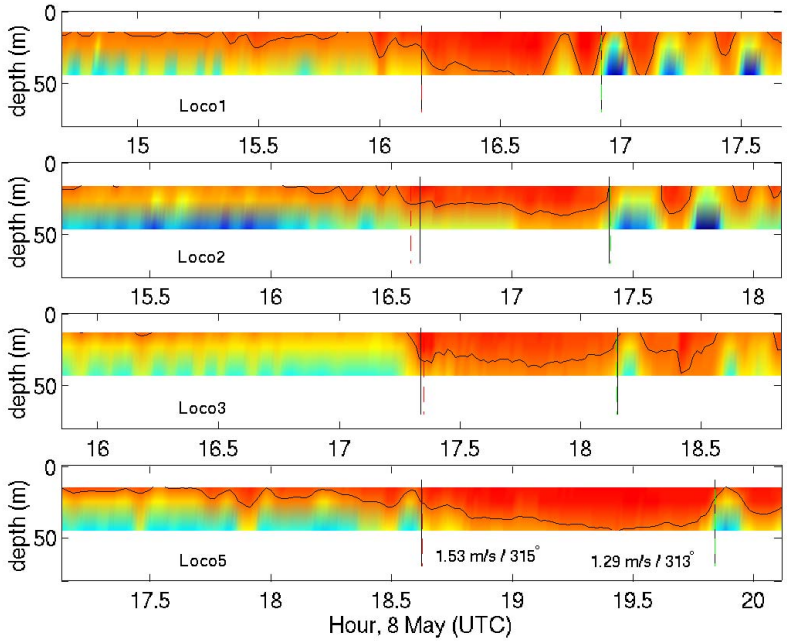

Figure 2. Temperature profile time series from four of the southern group Loco moorings are shown. The 26 degree isotherm is shown in black. The wave passes Loco 1 first and Loco 5 last. This figure is reproduced from the Duda et al. internal tide paper that has been accepted for publication. The warm depression wave in the center (displayed as red) was observed to propagate past the entire suite of mooring and was observed as a ~150-m amplitude wave of depression at the southern-most mooring in 350 water depth. Planar wave fronts with the listed speeds and directions have been fitted to the front and rear edges of the wave at these sites on approx 105-m of water. The single initial depression wave is rapidly evolving into a bore with trailing solitary-type waves in this section of the mooring array.

RESULTS

The HIWAY data and the other ASIAEX environmental data were processed and distributed to all project PI's under this project. An algorithm has been developed to find and count high-amplitude waves, which force isotherms to move past two or more vertically spaced sensors. The waves "census" follow a fortnightly pattern which does not match the local (measured) surface tide fortnightly cycle. Figure 3 shows a portion of this cycle., compared directly with one measure of acoustic signal variability. Isotherm displacements have been computed for all ASIAEX moorings, from which diurnal and semidiurnal internal tides can be extracted. Additionally, depth-integrated (mean) temperature has been used as a proxy for thermocline displacement; this converts easily into perturbation sound speed for comparison with ASIAEX acoustic fluctuations. This project and related projects have yielded many other results concerning barotropic tides, baroclinic tides, acoustic signal levels, acoustic signal variability, and nonlinear internal waves, many of which appear in the submitted and accepted papers listed below.

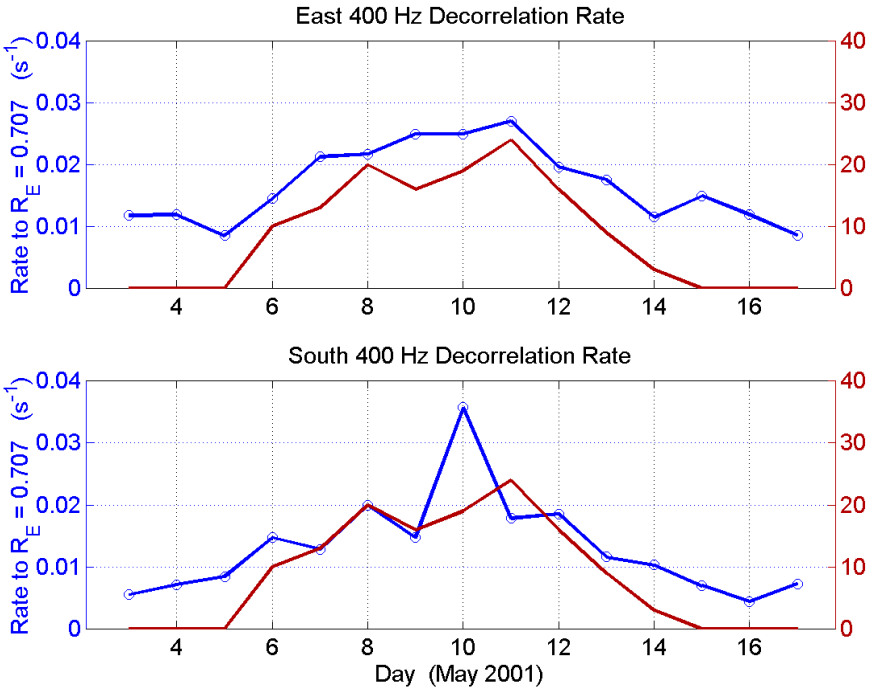

Figure 3. Two time series are shown: In blue, the inverse of the decorrelation time of incoherertly averaged 400-Hz acoustic signals measured by 16-channels of the VLA, and, in red, the daily quantity of internal solitary-type waves of amplitude greater than 20-m observed at one of the southern group Loco moorings located a few kilometers northeast of the HLA/VLA site.

IMPACT/APPLICATIONS

The strongest immediate impact of these data will come from comparison with Mid-Atlantic Bight data, and from comparison with our controlled acoustic signals. Some of the strong ASIAEX diurnal internal tides spawn trains of nonlinear internal waves, as were also seen in Mid-Atlantic Bight PRIMER and SWARM data. Quantitative assessment of internal wave properties and 200-600 Hz

acoustic signal variability is an important result obtained from the ASIAEX South China Sea Volume Interaction study.

RELATED PROJECTS

This project was undertaken under close collaboration with the ONR ASIAEX Volume Interaction Experiment (acoustics) under the direction of Dr. James Lynch, and the Frontal Studies in the South China Sea project of Drs. Gawarkiewicz, Beardsley and Brink, all of WHOI. There are many other related projects under the ASIAEX umbrella. Many of the projects of the Capturing Uncertainty DRI are also related. Related past projects are the SWARM and PRIMER acoustics/shelfbreak front internal wave/acoustic experiments, an acoustic/internal wave interaction modeling study of Duda and Preisig, and similar studies by other investigators such as Finette and Rouseff.

PUBLICATIONS

Newhall, L. Costello, T. Duda, J. Dunn, G. Gawarkiewicz, J. Irish, J. Kemp, N. McPhee, S. Liberatore, J. Lynch,, W. Ostrom, T. Schroeder, R. Trask, K. Von der Heydt, "Preliminary acoustic and oceanographic observations from the ASIAEX 2001 South China Sea Experiment", WHOI Technical Report WHOI-2001-12, Sept. 2001.

T. F. Duda, J. F. Lynch, J. D. Irish, R. C. Beardsley, S. R. Ramp, C.-S. Chiu, T. Y. Tang and Y. J. Yang, Internal tide and nonlinear internal wave behavior at the continental slope in the northern South China Sea, *IEEE J. Oceanic Engineering.,* in press.

T. F. Duda, J. F. Lynch, A. E. Newhall, L. Wu and C.-S. Chiu, Fluctuation of 400-Hz sound intensity in the 2001 ASIAEX South China Sea Experiment, submitted to *IEEE Journal of Oceanic Engineering*.

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S. R. Ramp, T. Y. Tang, T. F. Duda, J. F. Lynch, A. K. Liu, C.-S. Chiu, F. Bahr, H.-R. Kim and Y. J. Yang, Internal solitons in the northeastern South China Sea part I: Sources and deep water propagation, submitted to *IEEE J. Oceanic Engineering.*

R. C. Beardsley, T. F. Duda, J. F. Lynch, S. R. Ramp, J. D. Irish, C.-S. Chiu, T. Y. Tang and Y. J. Yang, The barotropic tides in the northeast South China Sea, submitted to *IEEE J. Oceanic Engineering.*